The following information was provided by

GLOBE™ Canada

GLOBECanada

Dendrochronology - the study of tree rings

GLOBE Canada affiliate scientist

Ms. Chris Marion

Chris Marion is a dendrochronologist with her own lab in Whitehorse, Yukon. Trained as a plant ecologist, Chris was first introduced to dendrochronology while working on an ecological study of the plant juniper in northern Quebec. Chris now applies dendrochronology to answer a range of ecological and historical questions. Recent studies of hers have focused on forest fire histories, as well as insect epidemics on forests, throughout Yukon, Northwest territories, Alberta and British Columbia. Chris has also applied the techniques of dendrochronology to date historic buildings and structures in Yukon. Chris enjoys the challenges of dendrochronology, which she describes as fun detective work!

TOP

Dendrochronology: Investigating the recent past

(the following text is prepared by Ms. Chris Marion. © C. Marion 2005)

Dendron (tree) + Chronos (time) = Dendrochronology: The use of tree rings as time markers

Dendrochronology can be a very powerful tool in answering ecological questions about the recent past. It also has applications in archaeology, geomorphology, forestry, climatology, and even law. This document is only an introduction to this technique; refer to Henri Grissino-Mayer's *Ultimate Tree-Ring Web Pages* (http://web.utk.edu/~grissino/) or to F. Schweingruber's 1988 *Tree Rings: Basics and Applications of Dendrochronology* for a much more comprehensive coverage of the technique and its many applications.

1) Introduction to wood anatomy and tree ring formation

Wood, or secondary xylem, is laid down in trees during the growing season to the inside of the cambium layer, accounting for lateral growth of trees.

A tree ring is composed of two (more or less distinct) bands of cells (figure 1). The earlywood, the light-coloured band, is laid down in the spring and early summer, when water availability is highest. The xylem cells produced by the cambium are then rather large in diameter, and have thin walls. Latewood is produced later on in the summer and in the early fall. Latewood cells are somewhat smaller than the early wood cells, and have a much thicker cell wall and much smaller lumen, accounting for the darker color of the latewood. At the end of the growing season, wood production shuts down until the following spring, when large, thin-walled cells are again produced by the cambium, making a very sharp contrast with the previous year's dark, tight latewood (at least in conifers!) (Figure 2).

Water availability and warmth of the growing season are the two main factors affecting tree ring width. A wet, warm season will lead to the formation of wide, light-coloured bands in most boreal evergreen trees, with ring width generally increasing with the length of the favourable growing season. Dry or cold summers will result in narrower rings. Although the trees' response to growing conditions is species-specific and also depends on other factors such as nutrient and light availability, the previous generalizations usually apply to most of our boreal conifer species. Deciduous species are more difficult to work with as the latewood is not much different form the early wood, and observation of the cells themselves is sometimes the only way to distinguish the annual rings.

Many events will happen in the life of a tree which may be recorded in its wood either at the cellular level or as more obvious scars or deformations in the tree itself. Frost, insect epidemics, and droughts are a few examples of events that will be recorded in the rings at the precise year (or series of years) at which they occurred. Fire and other cambium-destroying accidents will stop the production of wood where the cambium was damaged, leaving a scar that might eventually close with time; this scar can also be dated. Cutting down a tree will stop lateral growth altogether and tell us the year the tree was felled. Tree death by flooding, burying, or uprooting can also be dated.

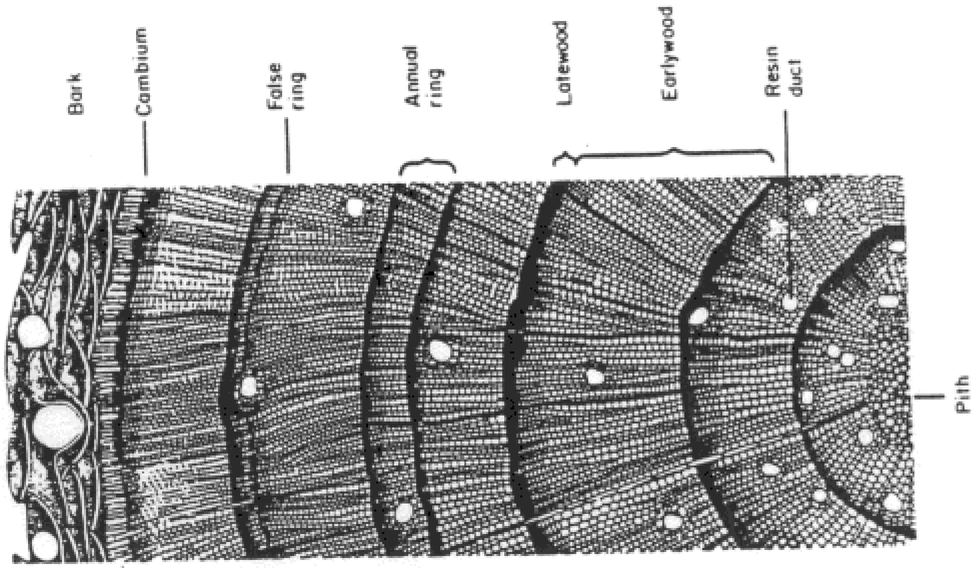

Figure 1. Cross-section of a young conifer stem showing wood structure. (From Fritts, 1979.)

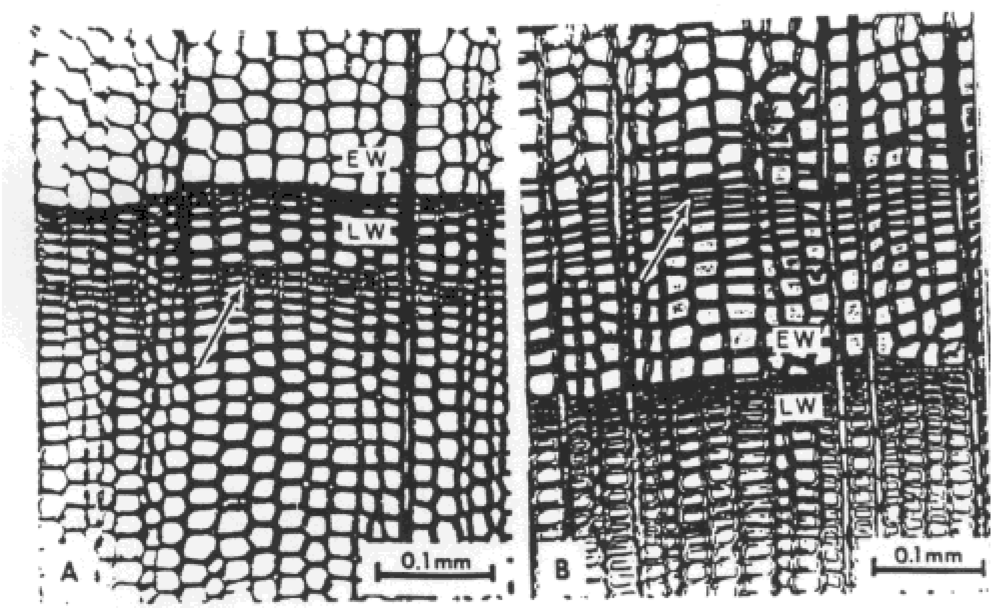

Figure 2. Annual growth rings showing earlywood (EW), latewood (LW) and false rings (arrows). (From Fritts, 1979.)

More positive events in the life of a tree will usually be recorded as a wide ring, pointing to an increase in growth rate; for example, an opening in the forest canopy following the death of a mature tree will allow understory saplings to grow better due to an increase in the availability of light, rain, and nutrients.

2) Sampling, preparation, and dating of wood material

The first step in any research project or study relying on dendrochronology for answers is to decide exactly what the question is we want answered. This is important as it will influence the species we will sample, the sites where we will sample them, the number of samples we need, and the kind of samples we take.

For example, a study wanting to investigate past outbreaks of the spruce budworm will involve sampling trees sensitive to defoliation by the insect (fir and white spruce) as well as trees that are not sensitive to it (pine) to distinguish the insect signal from any background climate signal. A project looking for links between tree-ring width and recorded rainfall to make predictions of past precipitation regimes will involve sampling trees that are very sensitive to variation in rainfall: species that need a lot of water, or trees growing on sites where water from precipitations is a limiting factor, will give the best indication of precipitation levels.

Sampling of the trees can be done in a few ways. It is possible to obtain cores from trees using an increment borer; this type of sampling does not kill the tree, but can be difficult if the trees are rotten. Careful crossdating of the samples collected this way is necessary, because very narrow or incomplete/missing rings may be missed since the cores represent only a small fraction of the trees' cross-section. Taking a tree disk (or 'cookie') is destructive but tree disks are the best samples as incomplete rings can be detected, narrow rings can sometimes be seen better somewhere else around the stem, and patches of rot can be avoided when dating the disk. Scar such as fire scars are almost impossible to date without a disk.

Back in the lab, wood samples must be dried, and then sanded carefully to make dating more easily. Dating live trees is very straightforward: the last year laid down is the current year's wood production. Counting back from the outside ring towards the inside of the disk will give an approximate age for the tree. (Trees are very rarely sampled at the root collar; therefore a few too many rings may be missing from the beginning of a tree's life. Sampling as close to the ground as possible helps avoid underestimating the age of a tree.) Counting from the inside out towards a scar will then allow dating of the scar. Dead trees can be crossdated with live trees to allow for age determination; crossdating is discussed in section 4 (skeleton plots).

The code illustrated in figure 3 is very useful in keeping track of the number of rings counted. Pencil marks are recommended over pinprick as they can be erased should a dating mistake be detected.

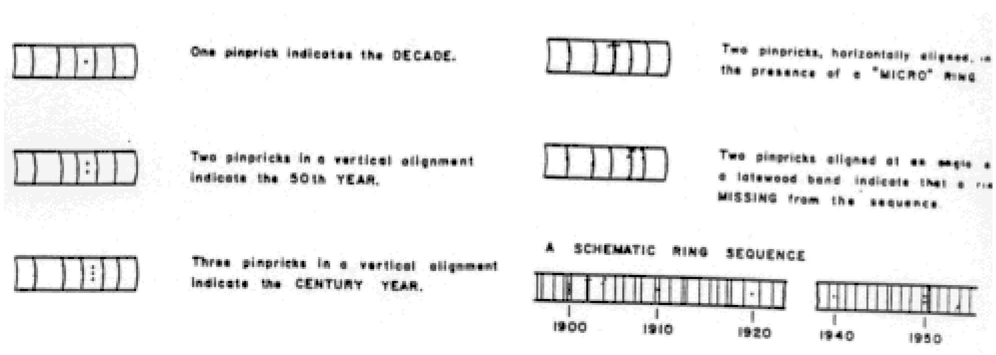

Figure 3. Keeping track of time using pencil marks on the rings. (From Stokes and Smiley 1968.)

3) Marker years

While most tree rings look more or less the same, some rings known as marker rings (or pointer years) may be conspicuously different from their neighbours. Such rings are useful for cross-dating; some of them even speak of localized or widespread disturbance events that are of interest to ecologists.

a) Frost rings

Frost rings are caused by late-spring or early-fall frost events. The cambium is affected by the cold, and a few layers of abnormal cells are produced before the cambium resumes its organized cell divisions. Frost rings appear as a band of darker, disorganized cells within a regular ring.

b) False rings and light rings

False rings happen when for a short period during the growing season, growing conditions resemble that of the end of the season, for example when drier and colder conditions prevail for several days. A few layers of thick-walled cells are formed, and they have the appearance of latewood. A close inspection of the suspicious ring will reveal that, although cell walls are thicker, cell size has not really decreased and the return to thinner-walled cells is progressive, not sharp like it would be if spring had just returned (see figure 2 for two examples of false rings).

Light rings, on the other hand, show minimal formation of latewood. A light ring may be hard to detect as the band of latewood can be very thin, very light, or even non-existent.

c) Incomplete/locally absent rings

Some tree species, for example larch, are notorious for having incomplete or even (locally) absent rings, most often due to high levels of defoliation by insects. In this case wood may be laid down only on whichever side of the tree has sustained the least defoliation, as photosynthesis might only happen there. Marker chronologies are very important in detecting absent rings; the only evidence that a ring is missing from a sample is the desynchronization of the following marker years with respect to the reference chronology.

d) Narrow rings

Narrow rings are the most useful of all marker rings. They appear faithfully in almost all of the trees of an area since they are usually caused by climate felt at a regional scale. Depending on the tree species in which they are recorded, they speak of drier/wetter or warmer/colder conditions than those preferred by the species. In Yukon narrow rings quite often correspond with fire years (dry years).

A series of narrow rings may indicate a few years of unfavourable growing seasons. It may also indicate an insect outbreak causing intense defoliation and therefore little growth; if that is the case, the series of narrow rings will only be present in the species that are affected by the defoliator, and other species will not show that insect signature.

4) Skeleton plots

All of the marker years described in the previous section are useful tools for building a reference chronology against which dead trees can be compared for crossdating purposes. The most common way to build such a marker year chronology is by drawing what we call a skeleton plot.

In a skeleton plot, marker years are recorded by a vertical line on a time axis (figure 4): narrower rings are represented by taller vertical lines. Narrow rings are the most reliable marker years to record in a skeleton plot, although frost rings, false rings and light rings are usually noted as well. In general, 15 to 20 samples will be enough to build a reliable skeleton plot. Marker rings are recorded on a separate time axis for each sample, then a composite skeleton plot for the site is compiled (figure 5).

Skeleton plots are very useful in identifying patterns of tree growth, and are quite often good enough to allow crossdating of most events and even date dead trees and wood samples. Unfortunately, a wood sample that happens to fall completely in between two reliable sets of marker rings cannot be crossdated in this manner. Skeleton plots also do not allow for climate reconstruction studies, as the picture they give is too coarse. This is when the need for master chronologies and computerised crossdating arises.

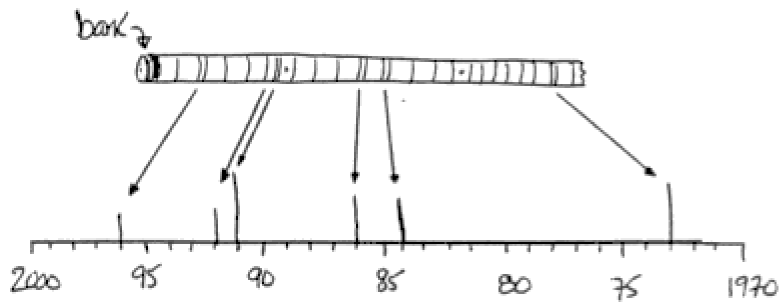

Figure 4. Narrow rings are recorded for each tree by a vertical line on a time axis; the narrower the ring, the taller the vertical line.

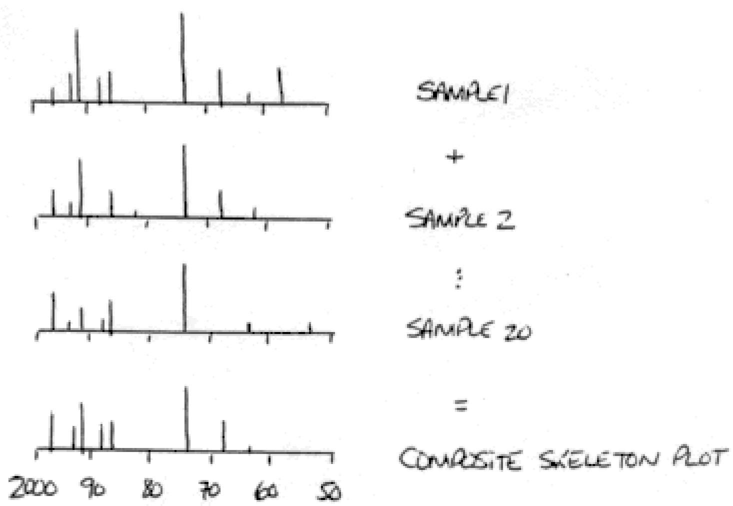

Figure 5. Compilation of the marker years from all the samples gives a reliable composite skeleton plot.

5) Master / reference chronologies

The creation of a master chronology for a specific area usually involves the sampling of many trees (>20). Ring widths have to be measured for every sample and every year, using a micrometer table or one of the software that allow on-screen measurements of digital samples. Dead trees and fossil wood that can be crossdated to the live-tree chronology can contribute to the building of very long master chronologies (figure 6). Those can be useful in reconstructing long-term climatic trends, or to date wooden structures and objects that were built or made a long time ago, if they are reasonably well preserved. Software such as COFECHA allow the comparison of ring width patterns in undated samples with dated master chronologies to find the best statistical match and therefore assign calendar dates to the undated samples.

Some master chronologies developed in Europe and in the south western United States can reach back as far as a few thousand years.

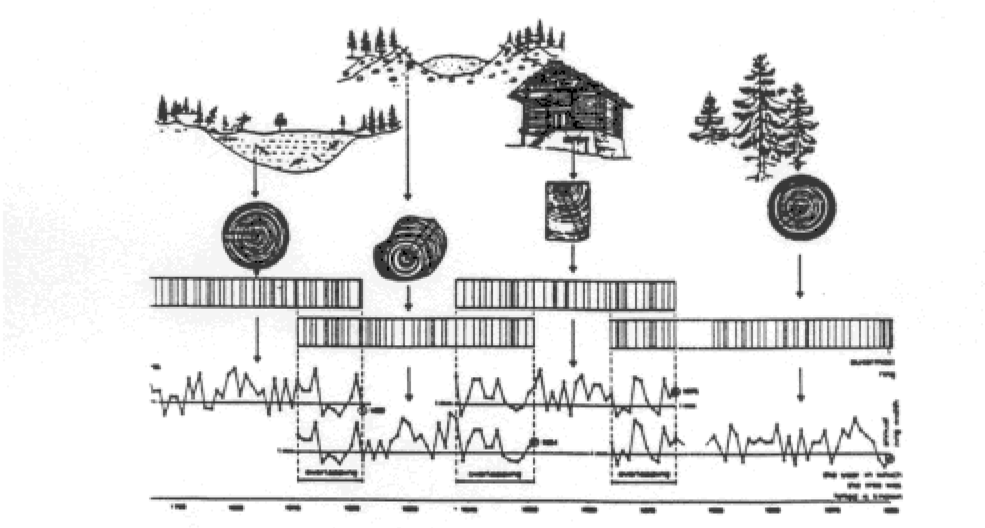

Figure 6. Cross-dating of live trees with dead or fossil trees allows the construction of long reference chronologies. (From Schweingruber 1988.)

6) Dating with wood: Some applications of dendrochronology

a) Wildfires (fire scars)

Surface fires in the boreal forest will quite often heat up some trees without killing them; the cambium will be destroyed on part of the tree's circumference, leaving a scar. Pine trees are notorious for surviving such fires, and may exhibit multiple fire scars. Trees on the edge of a burn may also be heated but not killed. In both cases the lateral cambium may be destroyed on part of the tree's circumference, leaving a wound (fire scar) that can be dated (figure 7).

b) Flood (ice scars) and avalanches (rock scars)

Ice floes carried by higher-than-usual rivers will sometimes damage the trees growing on the water's edge. Damage to the cambium will leave a datable abrasion scar. Similarly, avalanches and rock slides may leave trees scarred by rock scraping by; rocks may even become embedded in trees as the trees keep growing around them. Rock scars, like ice scars, can be rather ragged-edged and difficult to date, but they may provide a good estimate of the year of the avalanche or rock slide that caused them.

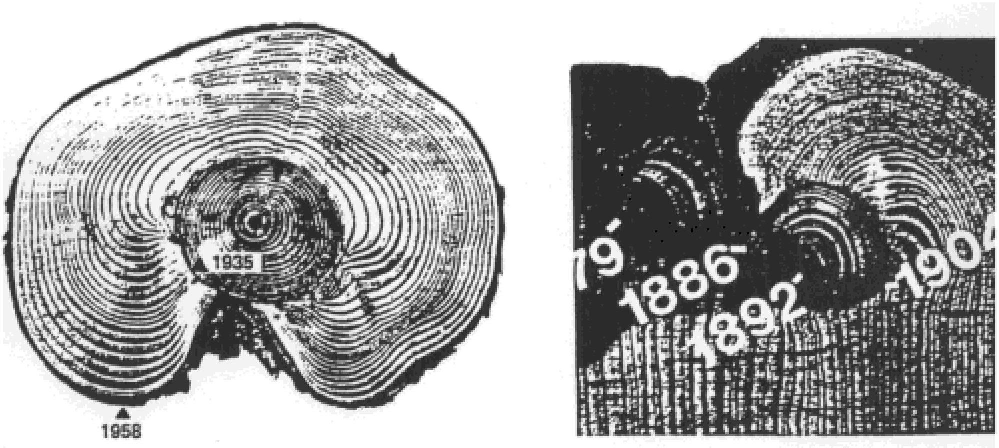

Figure 7. Fire-scarred trees can give us an accurate date of past fire events. (From Schweingruber 1988.)

c) Sand dune migration, floods (narrow/missing rings, dead trees)

As sand dunes migrate with time, they sometimes bury or partially bury the trees that happen to be in their way. If the trees die, their death can be dated. If they survive the migration of the dune, they will show much-reduced to no growth during the period of time when they were partially buried, then better growth as they get exposed later on, and the migration rate of the sand can be calculated. Thick sediment loads deposited around trees following a flood will also reduce tree growth or cause death. Adventitious roots growing out of the trunk following partial burial can also be dated.

d) Permafrost melting, slope erosion, avalanches (reaction wood)

Reaction wood is formed when a tree is tilted at an angle from the vertical. Trees on the edge of a patch of degrading permafrost, on the edge of an eroding slope, or trees tilted by the push of snow during an avalanche, will all exhibit reaction wood starting as soon as the event happens or in the following spring, if the tilting happened in the winter. Reaction wood is usually darker than normal wood, and appears only on one side of the tree for each tilt event.

Gymnosperms produce compression wood: the reaction wood is on the tilt side of the tree which tries to 'push itself back up (figure 8). Angiosperms form tension wood on the side opposite the tilt by trying to 'pull' themselves back up.

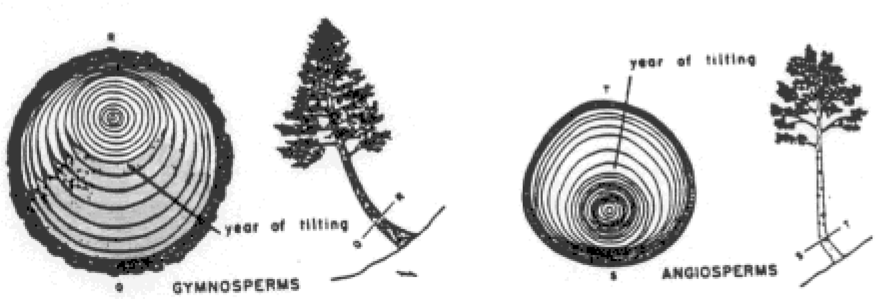

Figure 8. Tilted trees produce reaction wood in an effort to straighten up; gymnosperms produce compression wood on the tilt side of the tree, whereas angiosperms produce tension wood on the side opposite the tilt. (From Fritts 1979.)

e) Glacier advance, major ash fall, damming of lakes (dead trees, sometimes in-situ)

Dead trees that are found in-situ are most useful for dating such events, although boles that are found in moraines or at lake thrash lines can also be useful, with the caveat that they represent the latest date at which the event may have occurred (the trees may have been redeposited years after their death).

f) Opening in forest canopy, improvement in microsite conditions or climate (release rings)

Release rings may happen following a sudden improvement in climate or local growing conditions. They may also be formed following the crashing of an insect population which had been slowing down the growth of the affected trees. Any improvement in microsite conditions, such as opening of the forest canopy or major input of nutrients released by a fire, can also be reflected in the trees by the sudden production of wider rings (figure 9).

g) Climate reconstruction

Climate reconstruction is better done using actual measurements of tree rings, as the use of computer software for analyses requires precisely quantified variations in ring widths. Major climatic events such as the Little Ice Age (~1570-1850) usually show up in long reference chronologies. Ash and gas clouds from volcanic eruptions may also affect climate for one to many years, as will droughts. Recorded (recent) climate data are matched to the tree-ring chronology, and temperature and precipitations can be extrapolated to pre-documented years from the relationship observed between tree growth and climate during the time data are available.

h) Archaeological use for dating of wooden objects and structures

Dendrochronology has been used extensively in Europe and the south western United States, and is being used more and more in Canada and other parts of the world, to date the many wooden objects and structures left behind by earlier inhabitants. Structures and objects need to be in a good enough state of preservation, and their ring patterns need to be matched with a reference chronology from the area where the trees were harvested. Careful interpretation of the results is necessary to avoid assigning misleadingly old dates to younger buildings, particularly when the lumber may have been recycled from previously built structures as is the case in the American Southwest.

g) Salmon streams, radioactive clouds, other elements (molecular analysis)

Since trees incorporate molecules from their surroundings (both ground and air) into their annual rings, it is possible to date the apparition of new molecules in the system (e.g. radioactive elements after a nuclear accident, or pollutants of the industrial era) or track levels of nutrients in the soils (e.g. the nutrients contributed by dead salmon after spawning). Such studies involve the molecular analysis of annual growth layers (rings), and are just beginning to be explored, although it's already been a few years since tree rings were used to calibrate the radiocarbon scale and assign calendar years to ^{14}C dates.

TOP

References cited

Henri Grissino-Mayer's *Ultimate Tree-Ring Web Pages* (http://web.utk.edu/~grissino/)

F. Schweingruber's 1988 *Tree Rings: Basics and Applications of Dendrochronology.* D. Reidel, Dordrecht, The Netherlands, 276 pp.

TOP